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Assessing the value of coral reefs in the face of climate change: The evidence from Nha Trang Bay, Vietnam

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ABSTRACT

Coral reef ecosystems provide many important services to society. Their importance is not only proved by their beauty but also because they provide food and livelihood for millions of people in communities around the world, especially in developing countries. This paper estimates the economic value of coral ecosystems and potential impacts of climate change and fishing activities on the loss of coral reefs in Nha Trang Bay, Vietnam. Economic valuation and bioeconomic approaches are applied to combine socioeconomic data and projections of coral reef cover based on the quantitative scenarios of sea surface temperature and fishing activity to articulate the potential economic consequences of future change in the coral reef. The loss in economic value of coral under climate change and fishing effort scenarios is estimated which ranges from US$27.78 to US$31.72 million annually. This result is useful for policy makers to draw conclusions for climate policy, biodiversity conservation, sustainable development, and priorities for further work.

1. Introduction

Coral reef ecosystems provide many important services to society. Their importance is not only justified by their biodiversity and recreational value but also because they provide food and livelihood for millions of people in communities around the world, especially in developing countries. According to Wilkinson (2008), at least 500 million people in 109 countries depend directly on coral reefs for their economic well-being. Earlier studies estimate that coral reefs provide US $30 billion annually in goods and services that include fisheries, tourism, coastal protection, and intrinsic value (Moberg and Folke, 1999; Hoegh-Guldberg, 2004).

Despite the importance of corals, these habitats are being degraded due to a variety of factors including overfishing, coastal development, sedimentation, tourism overuse, climate change and acidification of the oceans (Edinger et al., 1998; Hallock, 2005; Mumby and Steneck, 2008; Brander et al., 2012). Among these factors, rising sea surface temperature (SST) as a result of climate change is one of the most serious causes of stress to corals throughout the world. The reason for this is due to the biological characteristics of corals as they survive only within a certain condition of temperature, light, and water chemistry conditions (Hoegh-Guldberg, 2004). These conditions are expected to change in the future due to the consequence of global warming and ocean acidification, which is caused by anthropogenic carbon dioxide emissions (Turley and Gattuso, 2012). Climate change also imposes challenges since the causality and effects are not easily relieved by local action or management (Hughes et al., 2003).

It is now widely recognized that climate change and coral reef economic value are linked (Chen et al., 2015). The change in coral reefs due to climate change and other threats can affect the flow of ecosystem services providing the benefits people obtain from ecosystems. These benefits include the Millennium Ecosystem Assessment's provisioning services (fishing and fishing-related activities and marine aquaculture), cultural services (tourism and education and research related to the marine environment), supporting services (primary production, nutrient, and water cycling), and regulating services (habitat provision for fisheries and other species, storm protection and beach erosion control, and many key environmental processes). Given the climate threats to coral reefs, an appropriate analytical framework for these threats requires the integration of natural science, economics, conservation, and public policies (Beaumont et al., 2008; Brander et al., 2007; Cesar, 2000; Chen et al., 2015).

Research on ecosystem services have grown gradually and gained broader attention throughout the past decade (McDonough et al., 2017). Monetary valuation and other types of ecosystem service information are often used as a measure of ecosystem service value to raise the awareness among users and provide information for managers and policy makers (Costanza et al., 1997; Wright et al., 2017). The methodology for qualification of ecosystem services is the main challenge in conducting research since it is difficult to capture all benefits of

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ecosystem services in unique circumstances (Hanley and Barbier, 2009; Beaumont et al., 2008).

A number of studies have quantified the economic value of coral reefs (Cesar, 2000; Brander et al., 2007; Griffen and Drake, 2008; Laurans et al., 2013) however, most of studies focus on a handful of coral reef ecosystems services such as provisioning services (Christina et al., 2014; Joelle et al., 2015), regulating services (coastal protection) (Zanten et al., 2014; Nalini et al., 2015; Pascal et al., 2016), cultural services (tourism and recreation) (van Beukering et al., 2015; Diane et al., 2017; Mark et al., 2017; Subade and Francisco, 2014), and the management aspect (Johnson and Saunders, 2014; Kelly, 2015; Ngoc, 2017, 2018). Only a limited number evaluate the impacts of climate change on coral reefs. Some authors investigate effects of ocean acidification damages to coral reefs (Brander et al., 2012; Speers et al., 2016). Others highlight the climate change impacts and adaptation options for reef fisheries (Cinner et al., 2012; Iliana et al., 2014).

Different valuation approaches have been developed and applied to address specific policy and management questions and to value coral reefs and marine ecosystem services. Three main perspectives on valuing coral reefs and marine ecosystems include economic, socio-cultural and ecological benefits (Fernandes et al., 1999; Laurila-Pant et al., 2015). The valuations can utilize the indicator systems (Yee et al., 2015, 2014; Kittinger et al., 2012) or use quantitative tools for assessing the value of coral reef ecosystems to provide information for improving management (Groot et al., 2012; Jarvis et al., 2017; Subade and Francisco, 2014; Grafeld et al., 2016; Fitzpatrick et al., 2017; Elliff and Kikuchi, 2017). However, the problem arising from the research is the interface between ecology and socioeconomic systems. The lack of scientific information on the ecology aspect (reef structural complexity, species richness, and fish population) may affect the economic estimates.

Vietnam has about 1300 km^2 of coral reef and is recognized as one of the countries where biodiversity conservation should be prioritized. However, there have been very few studies conducted on the valuation of coral reefs in Vietnam and the impacts of climate change on the value of these ecosystem are still largely unexplored. This study will use Nha Trang bay as a case study to investigate how climate change can impact the health of coral reef ecosystems and in turn lead to the loss in the economic value of coral reefs. Coral ecosystems in Nha Trang Bay play an important function in providing crucial goods and services to people living in this area. These goods and services provide a source of income for local populations through fishing, aquaculture, etc. They are also a tourist attraction, contributing to local income and cultural exchange. Coral reefs in the area have been assessed as having a high potential for tourism development. However, the pressure from natural and socioeconomic activities including fishing, tourism development, and climate change imposes serious threats to coral reefs, raising the need to consider the socioeconomic aspect in the management of coral reefs. Good management of coral reefs is necessary to maintain sustainable use and benefits to the community over time.

For the previous studies on valuation of coral reef in Nha Trang Bay, Nam and Son (2005) estimate and analyze the impacts on the recreational value of coral reefs by travel cost model and contingent valuation method. The research assesses economic impact of the port expansion and provides policy makers the knowledge about benefit of tourism compared to that of other activities. The result from this study shows that the expansion of the port in Nha Trang can lead to 20% loss in recreational value of coral reef. Implications for effective conservation program for coral reefs and management of Nha Trang bay MPA are thus provided.

In a recent assessment, Xuan et al. (2017) applies a discrete choice experiment to derive tourists' willingness to pay (WTP) for coral reef conservation and environmental quality in the Nha Trang Bay. The change in consumer surplus and the cost of management scenarios have been estimated to assess whether it is economically viable to conduct the new management scenarios. Their findings indicate that environmental protection and biodiversity conservation can be the good ecological policy and viable economic policy as well.

Our study contributes to the literature eliciting values for coral reef ecosystem services by implementing economic valuation of coral reefs to present an estimate of benefits and opportunities over time. Three key goods and services: fisheries, aquaculture, and tourism are valued. A bioeconomic approach with a modified logistic growth model is applied to evaluate the climate change impacts on the coral reef cover. The links between climate change to coral reef cover and coral reef value are also investigated to provide future scenarios of coral reefs under climate change predicted. Understanding this linkage is essential to draw conclusions for climate policy and biodiversity conservation to mitigate and adapt to climate change in the future.

The paper is organized as follows: the next section describes the study site and state of the coral reef ecosystem. Section 3 describes the overall methodology and data sources used. Section 4 describes the economic value of each of ecosystem services. This section also provides the potential loss of coral reef coverage and coral reef value under the impact of climate change and fisheries. The final section discusses the policy implications for coral reef conservation and sustainable development.

2. Background to the study site and the state of coral reef

2.1. Study site

Nha Trang is a coastal city and capital of Khanh Hoa Province, located on the South Central Coast of Vietnam. The city has a geographical area of 251 km^2 and population of about 500,000. Nha Trang is well known for its beaches and scuba diving. It is considered among the world's most beautiful Bays and a popular destination for Vietnamese and international tourists.

Nha Trang is a priority site listed in the Vietnam Biodiversity Action Plan and considered a biodiversity hotspot of the country. The area has a rich diversity of biological, ecological and landscape features. In 2002, Nha Trang Bay marine protected area was established, aimed at conserving biodiversity, focusing on coral reef ecosystems and enhancing local communities' livelihoods. The marine protected area encompassing nine islands is the first marine protected area in Vietnam (Fig. 1). It acts as a marine biodiversity conservation center with 160 km^2 that holds a special position in marine resource management and a demonstration project for other protected areas in the country. A number of resource management projects focusing on alternative income generation has been initiated by government agencies and foreign donors such as Ministry of Agriculture and Rural Development, DANIDA and WWF. Recently the Vietnam government has approved a major development plan in which Nha Trang Bay will become a special administrative economic zone by the end of this decade, with its role as a national and international ecotourism and entertainment center.

2.2. The state of coral reefs

Previous studies revealed that Nha Trang Bay has high marine biodiversity with 6 kinds of mangroves; 7 kinds of seagrass; 115 taxa of seabed fauna in seagrass beds; 504 coral reef creatures (Tuan et al., 2005). Coral reefs and seagrass in Nha Trang form a unique natural ecosystem, with important biodiversity. The total coral reef area in Nha Trang water is 730 ha with the percent cover of 22.3% (Ben et al., 2015). 40% of the world's coral species can be found in Nha Trang Bay (Tuan et al., 2002).

The assessment of marine biodiversity of Nha Trang Bay for the period 1994-1998 was initially undertaken by WWF and then carried out every year from 2002 to 2012 by Institute of Oceanography. These assessments were resumed in 2015. There were 8 sites monitored from 2002 to 2012 and 13 sites monitored in 2015. The results show that coral cover fluctuates and varies between monitoring sites. The coral

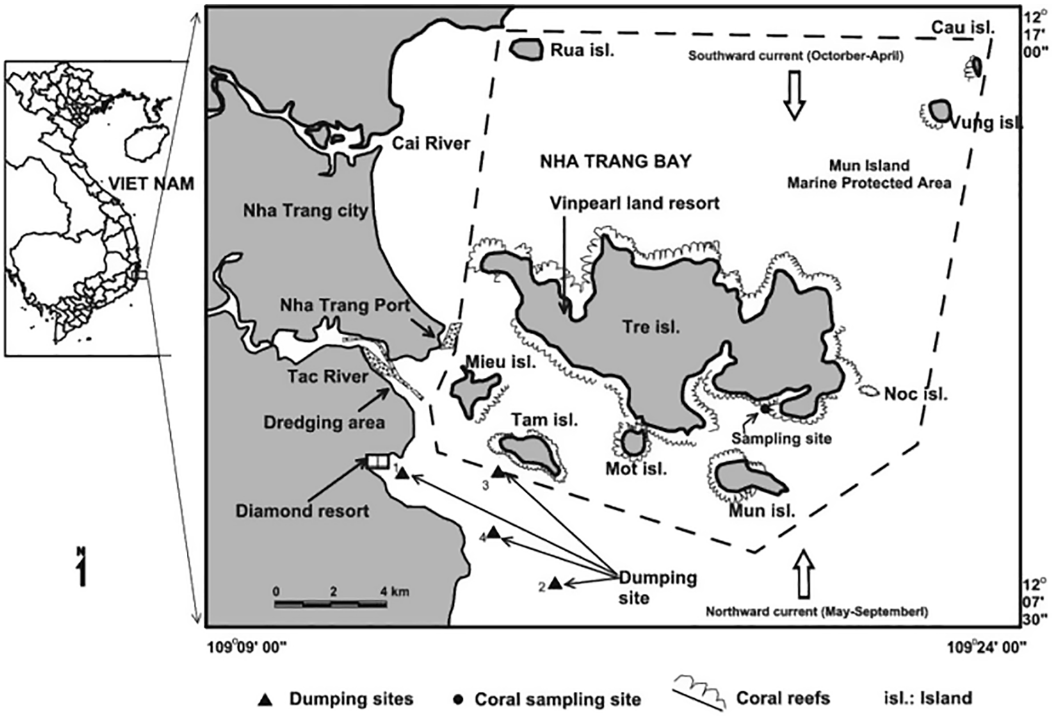

Fig. 1. The map of Nha Trang Bay (adapted from Nguyen et al., 2013).

reef cover in the core zone of the MPA is significantly higher than in outside areas. However, coral reefs in Nha Trang have been experiencing degradation, especially for close to the mainland due to a mixture of factors including overfishing, increase in sediments, the outbreak of crown-of-thorns starfish (COTS), climate change and tourism (Long and Phan, 2008; Tuan et al., 2004). The overall decline in hard coral cover during the last 20 years was 13% with a higher decline in the period of 1994–2000 (16.3%) compared to that in the period of 2000–2006 (2.6%) and 2006–2015 (0.9%). Notably, coral reefs in the Nha Trang region are at risk from global climate driven threats like coral bleaching which was recorded in Nha Trang Bay in 1998 and 2010, as well as ocean acidification, which has led to coral mortality in these years (Ben et al., 2015). A decrease in coral cover reduces habitat for fish and drives a shift in fish communities. Some reef fish species have declined in abundance, as has the catch (Long and Tuan, 2014).

3. Methods

To achieve our research objectives, we employ a mixed method design utilising both quantitative and qualitative methods. We combine the economic valuation, bioeconomic approach, scenario analysis and value transfer to investigate the impact of climate change and fishing activity on coral reef cover and due to this impacts on the coral reef value. The application of multiple methods can provide a comprehensive assessment of ecological and social economic dimensions of ecosystem services. While the economic valuation brings up the monetary value of coral ecosystem services, the bioeconomic approach with the logistic growth model can help to explore the consequence of climate change and fishing activity for coral reef cover. In addition, the scenario analysis and value transfer are conducted to investigate the linkage between the coral cover loss and coral value loss. The integration approach for this study does not only provide an understanding of ecosystem services and climate change but also capturing the interactions between dimensions. The framework for analysis is presented in Fig. 2. The procedure is implemented following steps:

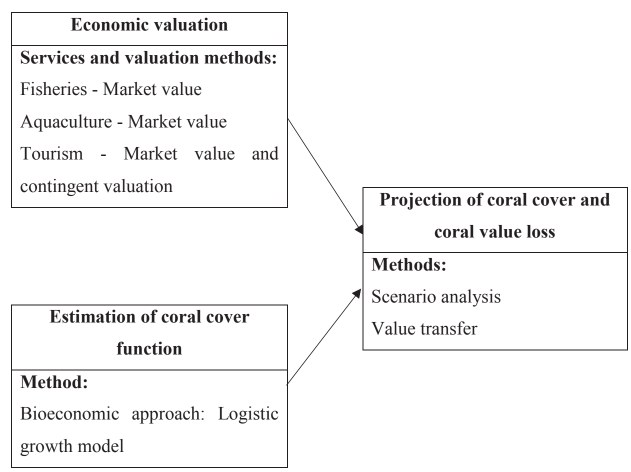

Fig. 2. Framework for analysis of coral cover and coral value loss due to SST and fishing activity.

Step 1 – *Economic valuation of coral reef ecosystems*: The economic value of coral reefs is assessed with three ecosystem services including fisheries, aquaculture, and tourism.
Step 2 – *Estimation of coral cover function*: The bioeconomic approach with the dynamic of carrying capacity in the logistic growth model is applied to estimate the coral cover function which indicates the change in coral reef cover given the change in SST and fishing effort.
Step 3 – *Projecting the SST and fishing effort impacts on coral cover and coral value*: Scenario analysis is used to project the SST and fishing effort. Their impacts on the coral cover is examined by using coral cover function estimated in step 2. The damage to the coral cover due to SST and fishing effort leading to the loss in the coral value assessed in step 1 is then measured by the value transfer, taking the elasticity showing the percentage change in coral value given a percentage change in coral cover from a meta-analysis.

3.1. The economic value of coral reef ecosystems

Goods and services resulting from coral reefs in Nha Trang waters are measured with monetary values by applying the concept of economic valuation (Pearce and Turner, 1990). The total economic value (TEV) of coral reef ecosystems is composed by use value and non-use value components. Use values are benefits proceeding from the actual use of the ecosystem, such as fisheries, aquaculture, tourism and beach front property values. Non-use values include an existence value, which demonstrates the value of an ecosystem to humans, independently of whether it is used or not, and an bequest value, where the ecosystem is preserved to ensure that future generations will be able to receive the same goods and services of the present generation.

Due to resource and budget constraints, in this study, the analysis does not cover all components of the TEV. As mentioned above, three major goods and services as the use value defined from the state of coral reef resources in Nha Trang are evaluated. These goods and services include fisheries, marine aquaculture, and tourism. Non-use value of coral reef goods and services is not examined in this analysis. Valuation techniques will be used in this study to compute economic value, including market value and contingent valuation.

Regarding fisheries and marine aquaculture, the market value approach will be applied to estimate the difference in the value of productive output as the basis of valuing coral reef services. Fishers were asked about the frequency of harvest, and on the average catch each time they went fishing. The component of the catch, the price, and the operation cost are also investigated to compute the value added of the fisheries. The aquaculture farmers were also asked about their production, selling price and relevant costs. From this information, the value-added of marine aquaculture is estimated.

For the tourism value associated with reefs, both producer surplus and consumer surplus will be examined. The producer surplus is calculated using market value approach by considering the value added of direct and indirect expenditure related to marine activities which include SCUBA diving and snorkeling, hotel and restaurant. The consumer surplus is defined by the contingent valuation method (CVM) which asks people what they are willing to pay for recreation benefits provided by coral reefs above what they actually spend. The payment card format is applied to elicit individual WTP. The respondents are provided a range of different money amounts and asked to choose the amount closest to their WTP. The mean WTP was calculated directly from the surveyed respondents by taking the average of the chosen amounts. Aggregation is obtained by multiplying the mean WTP by the annual number of visits.

3.2. Estimation of coral cover function

Changes in the coral cover can indicate the health of coral communities and are computed as the net difference between growth rates and the mortality rate of coral (Hughes et al., 2003; Hoegh-Guldberg, 2004). SST has been found to be an important determinant of coral reef presence and health. Many studies have shown this evidence (Hughes et al., 2003; Chen et al., 2015).

To investigate the relationship between climate and fishing activity and the coral cover extent, we apply logistic growth model for carrying capacity. The climate factor is SST and the socioeconomic condition includes fishing effort. The coral reefs provide the natural habitat for living creatures thus coral loss may also result in declines in habitat. This habitat is related to carrying capacity in marine areas. Some studies indicate that carrying capacity is influenced by habitat size and quality (Griffen and Drake, 2008; Hakoyama and Iwasa, 2000). Larger habitats and higher quality habitats can provide higher carrying capacities (Griffen and Drake, 2008; Hakoyama and Iwasa, 2000). The fishing activity and climate change can deteriorate the coral reef ecosystem and thus are also expected to impact the carrying capacity. The dynamic of carrying capacity is modeled as follows:

$$K_{t+1} - K_t = G(K_t) - \delta E_t K_t + \gamma SST_t K_t \tag{1}$$

which specifies the change in carrying capacity (K) as a function of the growth rate G of carrying capacity due to coral reef habitat change and the fishing effort (E) and SST impacts. The growth of carrying capacity is assumed to follow a logistic growth so $G(K_t) = \tau K_t(1 - K_t)$ as Narine et al., (2010), where τ is the growth rate of carrying capacity driven by coral reef habitat. Changes in coral reef cover may represent the carrying capacity changes over time. Based on the positive relationship between coral reef habitat and carrying capacity and following Barbier (2007), we assume K as a function of coral reef cover, represented by the coral cover (S).

$$K(S_t) = \alpha ln S_t \tag{2}$$

Substituting (2) into (1), the change in carrying capacity in relation to fishing activity and climate change can be defined as follows

$$\frac{lnS_{t+1} - lnS_t}{lnS_t} = \tau - \tau\alpha lnS_t - \delta E_t + \gamma SST_t \tag{3}$$

Parameters of the dynamics of coral reef ecosystems can be estimated with the coral reef cover, fishing effort and SST using transformation Eq. (3). This model estimate is derived under the assumption of long run equilibrium of the coral reef systems. The change in coral reef value EV impacted by coral cover S can be presented as follows:

$$EV_t = f(S_t \tag{4}$$

Eq. (4) can reveal how the change in SST and fishing effort can lead to the change coral reef value in the form of coral reef cover. To analyze this, scenario analysis with the value transfer is applied as shown in the following section.

3.3. Projecting the climate change and fishing impacts on coral cover and economic values of coral reefs

Eq. (3) allows us to estimate the impacts of SST and fishing effort on the coral reef cover while valuation framework provides the economic value of coral reefs in Nha Trang in 2015. The impacts of climate change and fisheries on coral cover and the economic value of the coral are then investigated. The projections of SST and fishing effort in different scenarios by 2065 are substituted into the coral cover function to estimate the coral cover. The percentage loss in coral cover is then computed. Due to the lack of past data on value of coral reef ecosystems in Nha Trang Bay, to investigate the relationship between coral cover and coral value, we will apply value transfer method. Value transfer methods are categorized into three major types: unit value transfer, value function transfer and meta-analytic function transfer (UNEP, 2013). The unit value transfer and value function transfer use the value estimated for an individual study site to calculate the value of an ecosystem service in the policy site. The meta-analytic function transfer applies the value function estimated from multiple primary studies for number of sites in conjunction with information of the policy site to estimate the unit value of an ecosystem service at the policy site. The meta-analytic approach thus can explicitly control for the specific characteristics of each policy site in the transfer process (UNEP, 2013).

In this study, the elasticity showing the change in coral value due to the change in coral cover from Chen et al. (2015) is taken to adjust economic value of the coral reef ecosystem in Nha Trang. Chen et al. (2015) apply a meta-analysis of 72 coral reef valuation studies to develop a transferable value of coral reefs. They assume a nonlinear relationship between coral cover and coral reef recreational and tourism value and estimate a quadratic function with the dependent variable being coral reef recreational value. The independent variables include the coral reef cover, the number of visitors to the reef sites per year, local annual GDP, tourist expenditures and a dummy variable for the region. By calculating the elasticity from the meta-analysis, it is shown that the coral reef recreation and tourism value decreased by 3.8%

Table 1
Coral reef ecosystem services, valuation methods, and data.

Aspects	Methods	Data sources
1. Economic valuation		
Fisheries	Market value	FGD, secondary data from IO, and household survey
Aquaculture	Market value	FGD, secondary data from DE, and household survey
Tourism	Market value for production surplus and CVM for consumer surplus	FGD, secondary data from DT, and tourism survey
2. Estimation of coral cover function		
Coral cover function	Bioeconomic approach (Logistic growth model)	SST from NOAA, Fishing effort from DARD, and the coral reef cover from IO
3. Projecting SST and fishing activity impacts on the coral cover and coral value		
Projecting the SST and fishing effort by 2065	Scenario analysis	SST from NOAA, fishing effort from DARD
Projecting SST and fishing effort impacts on coral cover	Scenario analysis Plugging projected SST and fishing effort into coral cover function to calculate the coral cover;	Projection of SST and fishing effort
Projecting coral reef cover loss on coral value	Scenario analysis Value transfer	Chen et al. (2015)

IO: Institute of Oceanography.
DE: Department of Economics.
DT: Department of Tourism.
DARD: Department of Agriculture and Rural Development.

when the coral cover was reduced by 1%. They also apply a crude proportion approach for other value factors of coral reefs so the loss of other value factors is assumed proportional to the loss of coral reef cover. We will combine our coral reef cover function (3) which can help to project the change in coral reef cover due to SST and fishing effort with the elasticity from the meta-analysis from Chen et al. (2015) to find the loss of coral reef tourism value due to the loss of coral cover under climate change and fishing effort scenarios. The loss of other value components (fisheries and aquaculture) is also computed based on the projected percentage loss of coral reef cover in Nha Trang Bay.

3.4. Data collection

Data was collected from different sources, including peer reviewed, reports, focus group discussions and household and tourist surveys. The secondary data included information on coral reef health, and a socioeconomic profile of local communities and resource users. The coral cover data were found in different sources, including Tuan et al. (2005) and Ben et al. (2015). The SST data was collected from NOAA (National Oceanic and Atmospheric Administration). Fishing effort measured by engine power in horsepower (HP) was obtained from the Department of Agriculture and Rural Development. This dataset contains records of the above variables for the 1994 to 2012 period and the year 2015.

A focus group discussion (FGD) was also conducted with the participation of different stakeholder groups, including government representatives, local communities, fishers, aquaculture farmers and tourists. The discussion produced the necessary information on characteristics of aquaculture and fisheries activities and various types of costs and revenues that could help for the design of the household survey and identified the major threats to the coral reefs and marine resources. Fishing, aquaculture, and tourism activities were also discussed to determine the relevant information regarding the importance of coral reefs and their contribution to the revenue and value added of these activities.

A face-to-face household survey was conducted with a sample of 27 aquaculture farmers and 128 fishers. This survey aims to investigate the production, the cost and the revenue related to fishing and aquaculture activities. From this information, the value added can be defined.

A questionnaire with the specific questions to tourists was elaborated and delivered to tourists to investigate the maximum WTP for their experience in Nha Trang Bay reef area. A stratified sampling was applied to select the sample. The respondents were first categorized into domestic and international tourist groups. Each group was then categorized according to the geographical regions. The domestic tourists were classified into three sub-groups including those from the Northern, from the Central and from the Southern regions of Vietnam. Foreign tourists were classified into three sub-groups including tourists from European, from Asia, and from other continents as 88.3% of foreign tourists visiting Nha Trang in 2015 come from European and Asia[1]. All of the parameters for distribution of the respondents are following the statistics of Department of Tourism of Nha Trang city. In total, 145 out of 150 respondents provide valid and adequate answers. 109 of whom are domestic tourists comprising 37 people from the North, 45 people from the South and 27 people from the Central. There are 36 foreign tourists of which 17 people from Europe, 13 people from Asia, and 6 people from other continents. A summary of data for this study can be seen in Table 1.

4. Results

4.1. Economic value of coral reefs

4.1.1. Fisheries

The fishing fleet in Nha Trang comprises a variety of vessels, utilizing 11 different types of gears and techniques. The most popular fishing method to catch fish in Nha Trang is longline and gillnet, used to catch a broad variety of fish, shrimps, and mollusk. Fishers are dependent on reefs for fishing and viable marine-based ventures. There are more than 2000 vessels operating in the Nha Trang Bay. In 2015, the fleet landed 10.3 thousand tons of different type of fish with a total value added of US $15.03 million[2]. From our household survey with fishers, the ex-vessel prices of these fishes ranged from US$1.2/kg to US $7.16/kg.

Some qualitative and quantitative data and information related to reef fisheries have been mentioned in several publications and technical reports at national (Tuan et al., 2005, 2007) and local scales (Tuan, et al., 2005; Long, et al., 2004). However, a recent analysis of fisheries related to coral reefs in some key areas in Vietnam indicates that coral reefs have provided high production of target resources.

Analysis by Institute of Oceanography of coral reefs in Nha Trang in 2015 shows that coral reefs in Nha Trang waters provided 324 tons of commercial species and 212,000 lobster seeds per year. Catch of ornamental fish such as butterflyfishes, angelfishes, wrasses, scorpionfishes etc., to supply the local and international aquarium trade have

[1] Source of number: Department of Tourism, Nha Trang city.
[2] Source of number: Department of Economics, Nha Trang city.

Table 2
Annual fishery value associated with coral reefs in Nha Trang Bay, 2015.

Species Group	Quantity	Total revenue (US$ million)	Value added (US$ million)
Reef-associated fishery (tons)	324	0.89	0.62
Lobster seeds (individual)	212.000	2.99	2.09
Ornamental fish (individual)	1000	0.04	0.03
Total fishery value		3.92	2.74

Table 3
Annual aquaculture value associated with coral reefs in Nha Trang Bay, 2015.

Species Group	Quantity (tons)	Total revenue (US $ million)	Value added (US $ million)
Lobster	220	13.08	4.97
Grouper	37	0.41	0.13
Total aquaculture value		13.49	5.10

been recorded in many areas during the last decades. The number of ornamental fish collected from Nha Trang Bay for transportation to aquaria in Ho Chi Minh City was around 1000 fish annually (Long and Tuan, 2014). The value added of fisheries associated to coral reefs from our fisher survey is 70% of revenue and is shown in Table 2. The annual value added from fisheries is estimated to be US$ 2.7 million.

4.1.2. Marine aquaculture

Marine aquaculture with cage culture systems has grown rapidly in Nha Trang Bay and is seen as contributing to food security, poverty alleviation, and export value. Unlike freshwater aquaria species, where most of these species are currently farmed, the great majority of marine aquaria species is stocked from the wild. Reef-dependent species often include various species of shrimp (e.g., Penaeus spp.), snapper (e.g., Lutjanus spp.), grouper (e.g., Epinephelus spp.), wrasses (e.g., Cheilnus spp.), conchs (e.g., Strombidae), mullets (e.g., Mugil spp.) parrotfish (e.g., Scarus spp.), porgies (e.g., Calamus spp.), and others (Long and Tuan, 2014). Lobster and grouper are the major marine aquaculture commodities in Nha Trang. The seed of lobsters and groupers still depends on the wild caught seed and brood stock. In this study, reef-–related aquaculture is computed based on the value added of lobster and grouper production. In 2015, production from marine aquaculture systems in Nha Trang Bay was 37 tons of grouper and 220 tons of lobster[3]. The value added for lobsters and grouper from our household survey is 38% and 32% of total revenue, respectively. The average prices per kilo for the lobster and grouper is US$ 59.433 and US$ 11.087, respectively. The value added of aquaculture associated to coral reefs is estimated to be US$5.1 million as shown in Table 3.

4.1.3. Tourism

A variety of tourist activities take place in Nha Trang Bay. These activities include SCUBA diving, snorkeling, swimming, sunbathing, some recreational fishing and visiting fishing villages. Since 2000, the tourism sector of Nha Trang has a colossal growth in an expanding market. The number of international visitors staying in Nha Trang is higher than the average level of the country. Our tourist survey revealed that about 90 percent of the tourists visiting Nha Trang participate in beach/marine recreation activities. Tourism in Nha Trang is reported by the Department of Tourism, Sport, and Culture with 974,000 foreign tourists and 3,097,000 domestic tourists in 2015, contributing a total revenue of USD321.1 million.. A conservative measure of about 600,000 people[4] (accounting for 14.3 percent of the total visitors to Nha Trang) visiting coral reef sites including people participate in scuba diving, snorkeling and glass bottom boat. The average tourist expenditure per day for foreign and local visitors was US $ 97.83 and US$ 52.81, respectively.

We compute the tourism value of reefs in Nha Trang including producer surplus based on tourism revenue and visitors' consumer surplus reflecting the amount that visitors have been willing to pay in addition to the actual payment to enjoy the reef of Nha Trang Bay. The tourism revenues associated with reefs include direct revenues (e.g., diver fees and park entrance fees) and indirect revenues (e.g., lodging and resort accommodation, dive operations and restaurants). And this value is estimated based on the number of tourists visiting coral sites (600,000 people). The discussion with people from Department of Tourism, Sport, and Culture and tourist agencies also revealed that 45 percent of revenue can be considered as value added. This gave the value added of tourism associated with reefs of about US$ 21.11 million.

The consumer surplus is estimated by the contingent valuation from the tourism survey. We asked the question, If you were traveling to Nha Trang, what is the maximum amount that you would be willing to pay per person in addition to actual payment for your scuba diving, snorkeling or glass bottom boat experience? The amount ranges from US$ 1–20 for domestic tourists and US$ 2–35 for foreign tourists. From our survey, it revealed that the mean amount that the tourists would be willing to pay is US$3.52 and US$11.01 for domestic tourists and foreign tourists, respectively. Among 600,000 tourists visiting coral reef site, 60,000 tourists are foreigners (Walton, et al., 2015). This gives an estimate of the consumer surplus to be US$2.56 million. The value of coral reefs for tourism along Nha Trang Bay has a potential net annual return to the local economy of US$23.67 million (Table 4).

4.1.4. Economic value

The economic values of the individual coral reef associated goods and services are aggregated to give the economic value for the Nha Trang Bay coral reef ecosystem. The economic value for three key ecosystem services of the coral reef is US$ 31.51 million/year. Tourism, aquaculture, and fisheries generate annual direct use values from the coral reefs of US$23.670 million/year, US$5.10 million/year and US $2.74 million/year, respectively (Table 5). Economic valuation is a useful tool that can provide awareness about the economic value of coral reef ecosystems. Nha Trang Bay coral reef, which covers an area of approximately 730 ha, confers significant economic benefits to local communities and national economies.

4.2. Empirical model estimate result of the coral reef cover function

The coral reef cover function (3) was investigated first to examine the SST and fishing activities that may have influenced the coral reef cover. The descriptive statistics of variables and a correlation matrix are shown in Tables 6 and 7. The data on coral cover, and SST and fishing effort were gathered for nineteen- year period. The negative sign for SST and fishing effort in the correlation matrix denotes that for every variation in these variables, opposite variation in coral cover is produced. The climate change and socioeconomic conditions will impact the future coral ecosystem.

A regression analysis is conducted and validation of the predictive model is assessed. The inclusion of the lagged dependent variable

[3] Source of number: Department of Economics, Nha Trang city.
[4] Source of number: Management board of Nha Trang Bay MPA.

Table 4
Annual tourism value associated with the coral reefs in Nha Trang Bay, 2015.

	Consumer surplus	Producer surplus	Total tourism value (US$ million)
Mean WTP of domestic tourists (US$)	3.52		
Mean WTP of international tourists (US$)	11.01		
Total tourism revenue (US$ million)		321.1	
Total tourism revenue associated with coral reef (US$ million)		46	
Value added (US$ million)	2.56	21.11	23.67

Table 5
Annual economic value of coral reefs in Nha Trang Bay, 2015.

Goods/Services	Amount (US$ million)
Fisheries	2.74
Aquaculture	5.10
Tourism	23.67
Total	31.51

Table 6
Description statistics on variables.

	Coral (%)	SST (°C)	FishEffort (HP)
Mean	24.99	26.94	29,282.15
St. Dev	4.59	0.33	13,026.89
Min	18.5	26.26	9566
Max n = 19	35.1	27.48	45,634

Table 7
The correlation between the variables for coral cover, SST and fishing effort.

	Coral	SST	Fish Effort
Coral	1		
SST	−0.609	1	
Fish Effort	−0.894	0.463	1

Table 8
Estimates of model parameters.

	Coefficients	Standard Error	t Stat	P-value
Intercept	1.657346	0.515672	3.213955	0.005796
LagCoral	−0.19896	0.064799	−3.07035	0.007774
SST	−0.03603	0.015738	−2.28931	0.03698
FishEffort	−1.8E-06	9.49E-07	−1.88495	0.07896

requires the Durbin-h statistic to test the presence of serial correlation. Regression results give the value of $nS^2 < 1$, so we can compute the Durbin – h test. The adjusted coefficient of determination, R^2 is also used for validation assessment of the model. The R^2 equals 0.49 and the Durbin – h test equals 0.882 showing that the model is valid.

The regression estimates displayed in Table 8 indicate that the SST and fishing effort level significantly impact negatively on the coral cover and on change of carrying capacity. The coefficients for SST and fishing effort show the change in coral cover given a change in SST and fishing effort. Our model also accounts for expected lagged coral cover effects on the change in carrying capacity. Results show that a one period lag effect of coral cover also impact the carrying capacity or coral reef habitat. The parameter estimates in Table 8 were used to generate the parameters of coral reef ecosystems and fisheries which are reported in Table 9. These parameters can be used to compute the coral cover given observed values of SST and fishing effort which provides useful information for better management strategies and policies of this ecosystem.

Table 9
Parameters of the Nha Trang Bay coral reef ecosystem and fisheries.

Parameter	Symbol	Value
Growth rate of carrying capacity	τ	1.657346
The coral reef effect on carrying capacity	α	0.120047
Catchability coefficient	q	1.8E-06

Table 10
Scenarios for SST and fishing effort.

Increase in SST per year		Increase in fishing effort per year	
SST scenario 1 (BAU) SST increases with the trend during the past 20 years	0.031 °C	*Fishing effort scenario 1 (FE1)* Fishing effort increases with the trend of the period 2008–2015	635 HP
SST scenario 2 (110%BAU) SST increases by 10% compared to scenario 1	0.0341 °C	*Fishing effort scenario 2 (FE2)* Fishing effort increases by 80% compared that of scenario 1 due to the expand of the MPA	508 HP

Scenarios for projecting the loss of coral cover and coral value due to SST and fishing activity.
1. BAU-FE1, 2. BAU-FE2, 3. 110%BAU FE1, 4. 110%BAU-FE2.

4.3. Climate change and fisheries impacts on the coral cover and economic value of coral reefs

In order to allow quantitative valuations of potential impacts of climate change and fishing activity on coral reef value, we modelled SST and fishing effort in 50 year time (i.e. for 2065) informed by the qualitative scenarios. We evaluate the impact of climate change and fishing activity on coral reef cover and on the coral reef economic value.

We make some key assumptions. For SST, we assume two scenarios (Table 10). In the first scenario, the SST is assumed to increase by 0.031 °C per year, the same as the trend during the past 20 years (BAU). In the second scenario, we assume the global warming intensifies. Cheng et al. (2017), by using advanced climate computer model to re-investigate ocean heating from 1960 to 2015, show that ocean warming is about 13% faster than previously thinking. They also indicate that the warming has accelerated. We assume in our case, the SST increase 10% more than the trend in the last 20 years (110%BAU).

For the fishing effort, we also make two assumptions (Table 10). For the first scenario, the fishing effort is assumed to increase with the trend over the time period 2008–2015 by 635 HP per year (FE1). We choose this rate since from 2008 the Vietnamese government implemented a fuel subsidy for offshore fishing vessels. A credit program for offshore vessel construction with low interest was also developed. These two programs and the degradation of nearshore fishery resources led to the decrease in the number of new onshore small scale vessels built since 2008. For the second scenario, based on the plan for increasing the size of the core zone of Nha Trang Bay up to 30% of the whole MPA (the present size of the core zone accounts for 10% of the whole MPA) and

Table 11
Loss in coral reef value related to fisheries, aquaculture and tourism in 2065 due to the projected SST and fishing effort in millions of year the 2015 US dollar.

Goods/services	SST		Fishing effort	
	BAU	110%BAU	FE1	FE2
Projected SST (°C)/Fishing effort (HP)	28.85	29.00	76,949	70,034
Percentage loss in coral cover (%)	15.53	16.90	15.55	12.89
Reduction in coral reef value (US$ million)				
Fisheries	0.43	0.46	0.43	0.35
Aquaculture	0.79	0.86	0.79	0.66
Tourism	13.96	15.20	13.98	11.59
Total	15.18	16.52	15.20	12.60

for more conservation effort implemented in the next years (Xuan et al., 2017), it is assumed that the fishing effort just increases by 80% compared to that of the first scenario and equals 508 HP per year (FE2). Substituting the SST and fishing effort from quantitative scenarios into (3) allows us to estimate the change in coral reef cover given the change in SST and fishing effort. The tourism coral reef value change due to coral cover change is estimated based on the elasticity result from the meta-analysis of Chen et al. (2015). Thus the loss of tourism coral reef value is computed using the percentage loss of coral reef cover times the elasticity of 3.8 and then times the tourism coral reef value. The loss of other value factors including fisheries and aquaculture will be calculated using the percentage loss of coral reef cover times the value of each component.

The percentage changes in coral cover and in coral reef values due to the change in SST and fisheries in 2065 are shown in Table 11. The projected loss of tourism value ranges from US$11.59 million to US $15.20 million while the projected loss for fisheries and aquaculture ranges from US$0.35 million to US$0.96 million. The scenario 2 for SST with 10% higher in temperature compared to that of present trend causes the largest loss for the coral reef cover and coral reef value. Our estimation results indicate that the data support the theoretical assumptions and that in addition to fisheries, climate change is also a key predictor of overall coral reef ecosystem health.

The combined loss of coral value due to both climate change and fisheries is shown in Table 12 and Fig. 3. There are four possible scenarios including i) BAU and FE1, ii) BAU and FE2, iii) 110%BAU and FE1, and iv) 110%BAU and FE2. The total coral value loss ranges from US$27.78 million to US$31.72 million annually.

5. Discussion and conclusions

The successful management and conservation of coral reefs are dependent on a comprehensive understanding of the goods and services that they provide. With a wide range of goods and services provided by coral reefs in Nha Trang Bay, significant social and economic benefits have been obtained. The findings from this study provide insight into coral reef value and the impact of climate change and fishing activities on coral reefs. The value of coral reefs in Nha Trang Bay is US$31.51 million per year not only indicate their benefits to society but also informs management regarding possible negative relationships between climate change and fisheries, and coral reef health. Understanding this linkage could help to improve coral reef conservation and sustainable use of the coral reefs.

Among the use values of coral reef, tourism contributes the largest source of revenue for Nha Trang city and is the fastest growing industry. Nha Trang attracts tourists year round, and the number of tourists arrivals increased by 18% annually from 2011 to 2015[5]. The development

[5] Source of number: Department of Tourism, Sport, and Culture.

Table 12
Loss in annual coral reef value in 2065 due to the projected SST and fishing effort in millions of the year 2015 US dollar.

Coral reef value loss	BAU-FE1	BAU-FE2	110%BAU-FE1	110%BAU-FE2
Fisheries	0.86	0.78	0.89	0.81
Aquaculture	1.58	1.45	1.65	1.52
Tourism	27.94	25.55	29.18	26.79
Total	30.38	27.78	31.72	29.12

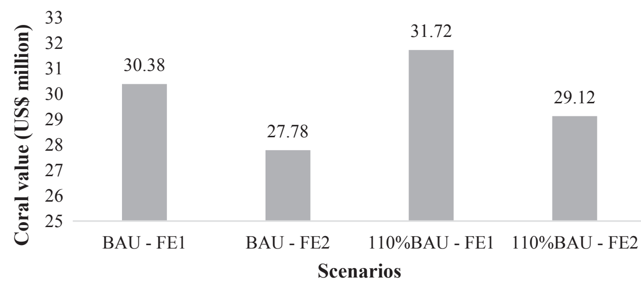

Fig. 3. The loss in coral reef value under combined scenarios of SST and fishing effort in 2065.

of tourism requires the development of tourist infrastructures such as building of roads, ports and airports, and hotel and resorts. This, in turn, generates the adverse impact of tourism on the natural environment. The tourism development has also led to higher demand for seafood consumption, which also increased pressure on fishery resources.

Environmental impacts of fishing and aquaculture on coral reefs should be also discussed. With around 2000 fishing vessels operating surrounding Nha Trang Bay, there is a concern about their possible impacts on coral reef ecosystems, especially with open access fisheries where fishers can catch as much as they want. This has long been recognized as a problem in the fisheries sector but also impacts the coral reef ecosystem and other coastal resources. The fishers depend mostly on the sea for their survival, and often lack formal education and alternative livelihood opportunities. This, in turn, further increases pressures on coastal resources. The use of destructive methods of fishing still exists in Nha Trang and damages the sustainability of fisheries and their habitats. In recent years, poaching has occurred inside the Nha Trang Bay MPA. The fishers invest in equipment to fish illegally and avoid being detected. The patrols hardly detect poaching since often the fishing vessels move outside the MPA, while in fact the net is located inside the protected area.

Regarding aquaculture, the use of trash fish as feed in aquaculture has effects outside the aquaculture industry. A growing demand for fish as animal feed for aquaculture leads to an increase in fishing effort on the wild fish stocks. Using fresh trash fish for aquaculture also leads to accumulation of anoxic sediments due to waste feed build-up. The environmental degradation and reduced water quality caused by aquaculture are becoming main threats to coral reefs and marine biodiversity in Nha Trang Bay.

By incorporating coral reef habitat into a logistic growth model through the carrying capacity dynamic, the results from this study have suggested that SST and fisheries have a significant negative impact on the coral reef cover. The analysis is based on the bioeconomic approach that widely applied to study for fishery resources (Ngoc, 2010). In this study, however, the model is modified with carrying capacity dynamics which depend on the coral reef habitat dynamics. This approach provides a foundation of knowledge to address the issue of coral reef conservation and management. The empirical estimation results indicate that climate change and fishing activity will influence coral reef cover and thus influence the carrying capacity. This clarifies the

importance of coral reef conservation and management. The fisheries resource cannot be preserved without the coral reef protection.

The loss in coral cover generates the loss in coral reef value. If the current trend in rising SST remains the same as the last 20 years, the coral reef cover will decline as much as 15.53% and the coral reef value loss will reach US$15.18 million in 2065 in which the coral reef tourism value loss will reach US$13.96 million. If global warming generates an even higher increase in the SST (10% more than the present trend), the coral cover will decline by 16.90% and the coral value loss peaks at US $16.52 million in 2065, increasing 8.83% compared to that of the present trend.

The analysis of linkage between fishing effort and coral reefs shows that fishing also imposes a high pressure on coral reefs. If the fishing effort increases by the rate observed over the period 2008 – 2015, the loss of coral cover reaches 15.55% and the economic loss for three ecosystem services reaches US$15.20 million in 2065. However if the fishing effort just increases at the rate of 80% of the level of the period 2008–2015, the loss in coral cover and coral value is lower, being 12.89% for coral cover and US$12.60 million for the coral reef value in 2065.

Climate change and biodiversity is interconnected. Climate change can affect the biodiversity and thus may influence goods and services crucial for human well-being. However, conservation and restoration of biodiversity can also support to reduce the negative impacts of climate change (MEA, 2005). The results from our research allow a demonstration of the economic consequences of climate change and fisheries on the coral reef ecosystem and the resulting economic outcomes. The message from our study is clear, to gain economic and environmental benefits from coral reefs, there is a need to have a more effective management of coral reef and marine biodiversity. This management must consider local threats such as overexploitation of marine resources and tourism and coastal development; and global threats, such as climate change. These issues are of concern since they may generate tradeoffs in terms of development and conservation; and development and climate change.

For the decision-making and policy planning in the coming years, marine spatial planning, focusing on effective marine resource use and coral reef conservation should be developed. Climate change and climate change adaptation options should be incorporated into the development strategy of fisheries and other coastal industries and considered as the key factor for sustainable development. This requires widespread support and participation by stakeholders at all levels of the administrative rung. Efforts to increase perception, awareness, and knowledge are urgent and critical for conservation and management of coral reefs and the well-being of the fishers, aquaculture farmers, industry, and urban population of Nha Trang.

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